Project: EOS/CERES Surface Radiation Validation at NOAA Climate Monitoring and Diagnostics Laboratory Field Sites

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1.0 Introduction

This project supports the collection and analysis of surface-based radiation budget observations at seven globally distributed sites operated by NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL). These data are useful in support of validation efforts of the EOS/CERES SARB and Surface-Only programs as well as the ASTER, MODIS and SAGE III program. Since the NOAA surface sites are part of the WCRP Baseline Surface Radiation Network (BSRN) program, considerable supporting data in addition to surface irradiance are also acquired which are beneficial to understanding many features of radiative transfer in the earth's atmosphere. The data collected under this project have been directly utilized by the programs flying onboard the TRMM satellite and are expected to provide validation for those programs on Terra.

2.0 Objectives

The objectives of this project are to sustain and improve ongoing surface radiation measurement capabilities that produce data necessary for validation of various EOS data streams. The intent is to build upon existing activities that already cover much of the cost and necessary logistic support to obtain such data at globally remote sites. Fundamental to the project were the enhancements of not only the existing observational capabilities but also augmentation of data processing and analysis to provide data on the rapid time scale desired by EOS.

A primary objective is to obtain surface irradiance data of sufficient quality and temporal resolution to meet the requirements of CERES and related climate research efforts. To help assure that such quality data are produced at the field sites supported in this project, these sites were upgraded towards satisfying the demanding specifications of the WCRP/BSRN program.

3.0 Activities and Accomplishments

Direct Solar Measurements

In-house testing of the all-weather absolute cavity radiometer was largely completed. Results suggest that wide spectral band pass (calcium fluoride) windows can be used on absolute cavity radiometers and preserve the inherent precision of these instruments. Similar testing was been performed on normal incidence pyrheliometers with calcium fluoride windows, but the results are still being evaluated. Field trials are planned as the next phase of the investigation (see *Planned Activities for FY2001* below).

Diffuse Measurements

An examination of the effects of longwave dome cooling in standard pyranometers and development of a compensation technique were brought near to completion. Formal publication of the results is expected during FY2001. Field trials of "black-and-white" pyranometers were initiated at CMDL's main facility in Boulder and at Mauna Loa. Both involve nearly side-by-side comparisons of these instruments with standard pyranometers and will continue into FY2001.

Infrared Measurements

The first International Pyrgeometer/Absolute Sky-scanning Radiometer Comparison (IPASRC - I), the first formal step in the development of an internationally recognized longwave irradiance measurement standard, was successfully completed in September 1999 at the ARM CART SGP site. The project involved the simultaneous deployment of an absolute sky-scanning longwave radiometer along with a suite of pyrgeometer for several weeks of observations. Additionally, longwave measurements were compared with modeled values obtained by using collocated sounding data as inputs to high-quality radiative transfer models. A significant issue arose when larger-than-expected differences (~ 5 W/m^2 in some cases) were found between the two models being used and is still being examined.

All-sky Digital Imaging and Cloud Cover

Three all-sky digital cameras were adapted for remote unattended operation and routine data processing. The systems were deployed at the Boulder Atmospheric Observatory and at Barrow. The third is presently operating at CMDL's main facility in Boulder. The images from these systems are acquired at one-minute intervals, analyzed in near real-time for cloud fraction during daylight hours and are archived for documentation and future analysis.

Data Evaluation

Enhanced quality testing was performed on each dataset prior to archiving the data for CERES use. Datasets are reviewed in detail for evidence of obstructions, tracking errors and signal failures. In addition, significant comparison testing is performed on the data. Examples are examining diffuse-to-direct flux ratios, comparing component sum calculations of total horizontal shortwave flux with global shortwave measurements, and comparing the downwelling global longwave flux with the emission of a blackbody at ambient temperature. These tests assist in identifying and isolating suspect data.

Work was completed on an improved technique for estimating the Rayleigh optical depth of the atmosphere. Rayleigh optical depth is essential to many atmospheric radiative transfer problems, for example, the estimation of lower bounds on downwelling diffuse fluxes (which is used in evaluating CMDL measurements as described above) and the determination of aerosol optical depths. The technique includes improvements in the calculation of molecular Rayleigh scattering cross-sections and in the calculation of the vertical column molecular number density (see *Publications* below).

4.0 Site Operations

All seven CMDL sites remain operational. Uninterrupted operation until the end of the contract period is essentially assured.

5.0 Data Acquired

The following summarizes the data acquired as part of this project

A. Direct solar, diffuse solar, global solar (independently measured) and global downwelling longwave irradiances (all seven sites)
   - one-minute averages with standard deviation of 1-Hz sampled data
   - available from before TRMM launch to present

B. Upwelling (reflected) solar, upwelling longwave irradiances (Boulder, Barrow, South Pole)
   - one-minute averages with standard deviation of 1-Hz sampled data
   - available from before TRMM launch to present

C. Spectral aerosol optical depth (Kwajalein, Bermuda, Mauna Loa, Boulder)
   - one-minute measurements
   - available from TRMM launch to present

D. UVB (Kwajalein, Bermuda, Mauna Loa, Boulder)
   - one-minute averages with standard deviations of 1-Hz sampled data
   - available from TRMM launch to present

E. PAR (Kwajalein, Bermuda)
   - one-minute averages with standard deviations of 1-Hz sampled data
   - available from TRMM launch to present

F. Local meteorological data including nearby upper air soundings

6.0 Data Processed

All of the above data have been processed to the level of applying preliminary calibrations (end-point calibrations are required for final processing) and first level editing. Data coincident with the TRMM CERES operations have been further processed to a research level product and have been forwarded to the CERES management and science teams.

7.0 Data Distributed, Access and Protocol

The research quality datasets described above are distributed to CERES as required, and are normally distributed in ascii or compressed ascii format. In addition, data from the designated BSRN sites (Kwajalein, Bermuda, South Pole, Barrow and Boulder) have been routinely submitted to the BSRN main data archive in Zurich. These data are available via the BSRN website at http://bsrn.ethz.ch. Data are also available to the research community from the CMDL archives on request, as has been done previously for EOS.

8.0 Publications and Presentations

The following publications and presentations from the prior year were at least in part related to the work done under this grant:

Bodhaine, B. A., N. B. Wood, E. G. Dutton, and J. R. Slusser, 1999: Note on Rayleigh optical depth calculations. *J. Atmos. Oceanic Technol.*, **16**, 1854 - 1861.

Dutton, E. G., T. Stoffel, J. Michalsky, D. Nelson, and J. Hickey: Measurement of broadband diffuse solar irradiance: an evaluation of some current capabilities. Presented at the Tenth Conference on Atmospheric Radiation, American Meteorological Society, Madison, Wisconsin, June 28 - July 2, 1999.

Dutton, E. G., J. J. Michalsky, T. Stoffel, B. W. Forgan, J. Hickey, D. W. Nelson, T. L. Alberta, and I. Reda: Measurement of broadband diffuse solar irradiance using current commercial instrumentation with a correction for thermal offset errors. *J. Atmos. Oceanic Technol.*, submitted, 1999.

Nelson, D. W., J. Hickey, N. Wood, and E. Dutton, Broadband direct solar beam measurements utilizing absolute cavity radiometers equipped with calcium fluoride windows. *Preprints, Tenth Conference on Atmospheric Radiation*, American Meteorological Society, Boston, MA, 1999.

9.0 Meetings Attended

A representative from the CMDL radiation program attended the CERES science team meeting held in April, 1999. In addition, personnel attended the American Meteorological Society's Tenth Conference on Atmospheric Radiation in June - July 1999 to present work related to this project.

10.0 Science Team Interaction

We have maintained frequent communications with the CERES science team and have had occasional discussions with the ASTER and MODIS teams. A direct and timely data transfer to the CERES program has been established with a mutual exchange of information concerning specific aspects of the data. We have worked with members of the CERES team to enhance observations at particular sites. Also, we have close ties to international organizations that are also acquiring surface irradiance data to be used by CERES and other EOS programs. We attend or are represented at nearly all CERES science team meetings. The NOAA/CMDL radiation program has many ongoing interests with members over a broad range of EOS climate and remote sensing activities.

11.0 Planned Activities for FY2001

This section reiterates the activities presented separately in the Statement of Work and Budget for FY2001.

Surface Radiation Datasets:

Production of high-quality data sets for utilization in the EOS/CERES validation efforts will continue through fiscal year 2001. These datasets include one-minute averages with standard deviations of 1-Hz data for direct solar, diffuse solar, global solar (independently measured) and global downwelling longwave irradiances at the surface. Additional data are as summarized in section 5.0 above.

Evaluation of algorithmic methods for data quality testing:

The enhanced quality testing performed on these datasets generally requires that an analyst review each dataset in detail prior to archiving. Prior work has suggested that some of this review could be adequately performed algorithmically, or that an appropriate algorithm could be used to identify data requiring further scrutiny. Work will continue on evaluating such algorithms.

Advancing instrument capabilities:

A number of investigations will be pursued which offer the possibility of improved measurement accuracy and which will be partially supported under this initiative. Within the first few months of FY2001, field trials will be initiated of an all-weather cavity radiometer and a normal incidence pyrheliometer (NIP) with a wide spectral bandpass window. The principal purposes of the field trials will be to determine the suitability of the window material for field use and to obtain side-by-side comparisons of the NIP versus a standard quartz-windowed NIP.

Examination of the pyranometer longwave dome cooling effect for diffuse measurements will continue. Current work is focused on an evaluation of "black-and-white" pyranometers, which seem to be much less susceptible to the negative bias typically caused by dome cooling.

Work will be performed on several fronts towards improving longwave measurements. As noted above, one element of IPASRC - I involved the comparison of longwave measurements with modeled values obtained by using collocated sounding data as inputs to two high-quality radiative transfer models, and a discrepancy (~ 5 W/m^2) between the models was detected. The differences between the models are being explored and will hopefully provide guidance as to appropriate model usage. A second longwave effort involves an analytical study of steady-state thermal balances within the pyrgeometer (being done in parallel with an examination of dome effects and instrument thermal-optical properties by Si-Chee Tsay and Qiang Ji at GSFC). It is expected that this work will lead to a better understanding of the calibration of the instrument and its performance under field conditions.

Other analysis efforts:

CERES' ERBE-like Instantaneous TOA Estimates product (ES-8) provides an additional opportunity to evaluate the quality of CMDL's data, particularly the surface downwelling longwave measurements. As described in the discussion of IPASRC - I above, model calculations can be used as a comparative tool for evaluating surface measurements, provided that the model calculations are appropriately validated. The CERES TOA estimates provide a set of independent data points with which the calculations can be validated and which, in turn, allow comparisons of the measured versus the modeled surface fluxes. A set of such comparisons will be initiated using clear-sky data from each of the CMDL sites, appropriate high-quality radiative transfer model calculations (incorporating nearly-collocated radiosonde data and aerosol information, where available) and the CERES TOA product. Immediate goals would be to determine what constraints can be placed on the model calculations via the TOA fluxes and identify how best to apply the model calculations in evaluating surface measurements.